<u>Computer Modeling Laboratory 6</u>

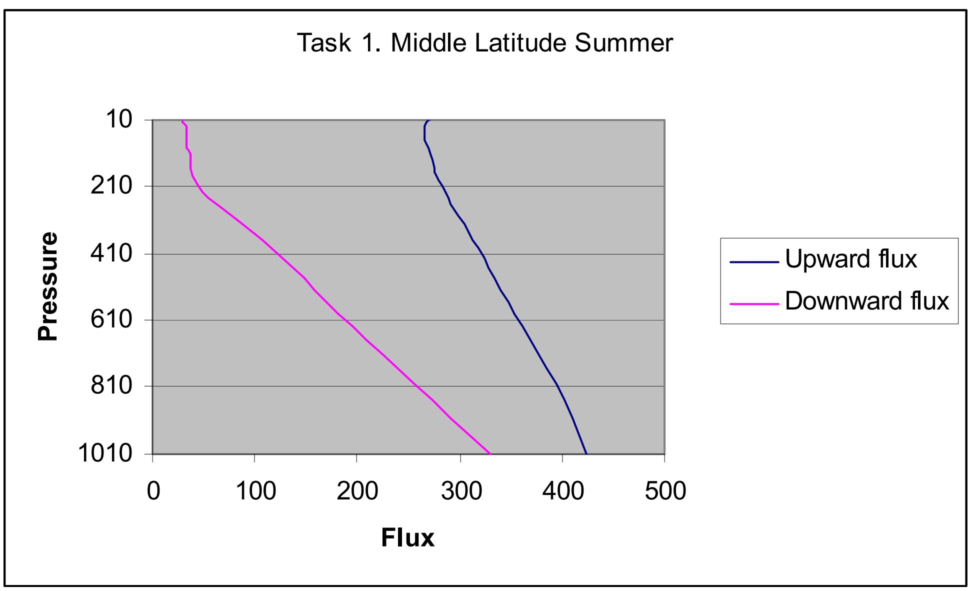
Written report due: Oct. 20

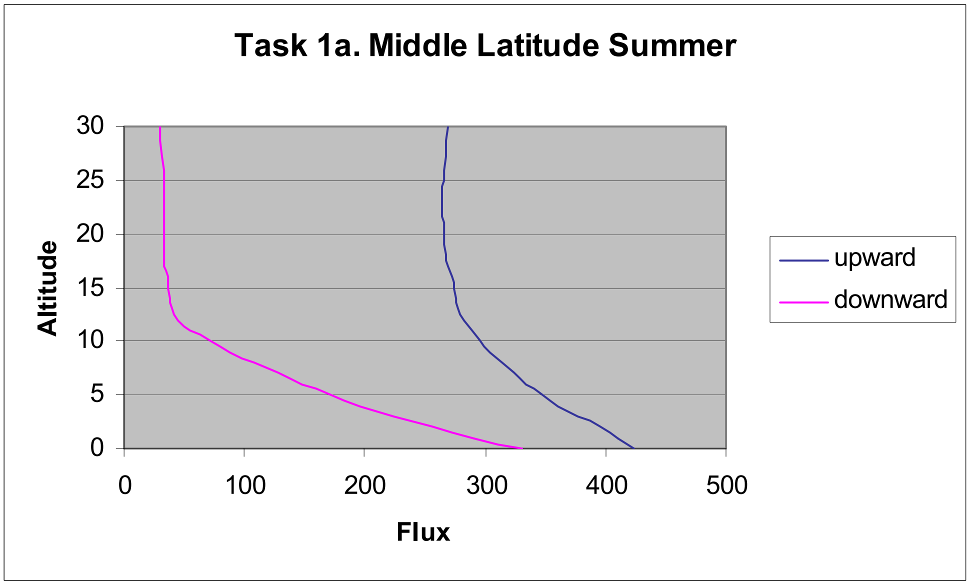
Modeling IR radiative fluxes and IR radiative heating/cooling rates in a gaseous atmosphere

Instruction: to calculate total IR fluxes and heating/cooling rates click on [RUN IR-RAD]

TASK 1

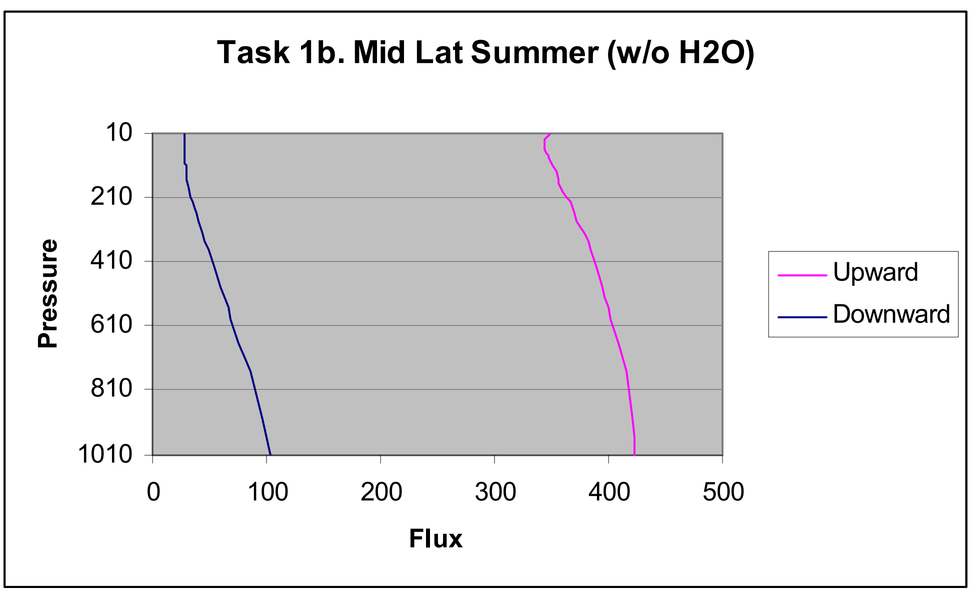
A) Calculate the IR upwelling and downwelling fluxes for the Midlatitude Summer Atmosphere. Plot them as a function of pressure (use about p=10 mb for the upper level so only the troposphere and stratosphere are plotted). For a different perspective, change the y-axis of the plots to altitude.
Why does the down-welling flux have a change in slope around 200 mb?





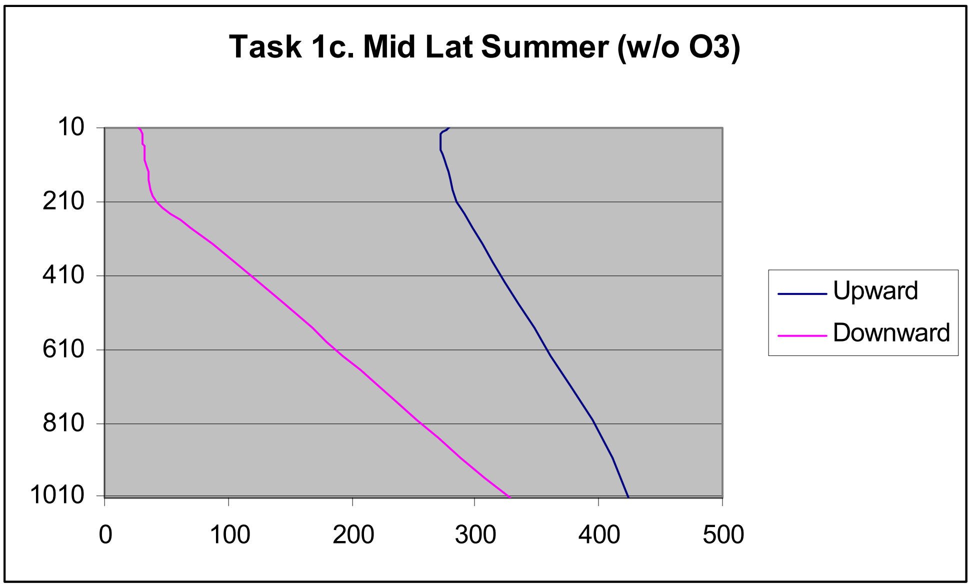
The tropopause is found at 200 *mb* or 12 km for the middle latitude summer atmosphere. In the troposphere (atmosphere below the tropopause) water vapor density is large, whereas above the tropopause there is much less water vapor. As water vapor concentration and temperature increases toward the ground, H2O emission also increases very rapidly and so is downward flux.

B) *Repeat the same calculations but with **H2O turned off**. Compare your results with case A. Explain the differences.*



When we turn off H2O, the sharp increase with pressure in downward flux disappears. This is because we removed the source for H2O emission. Moreover, the upward flux increases due to the lack of absorption by water vapor. Thus, atmosphere becomes more transparent to the radiation emitted by the warm surface. Besides, with no water vapor in troposphere, there is less cooling, thus tropospheric temperature increases and contribution to fluxes from CO2 and ozone emission relatively increases.

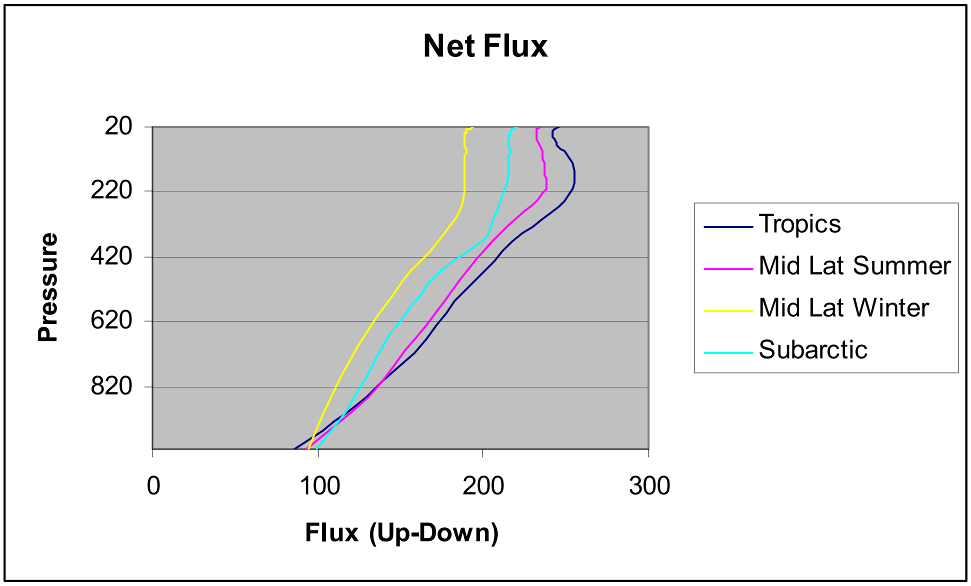
C) *Repeat the same calculations but with* ***O3 turned off****. Compare your results with cases A and B. Explain the differences.*

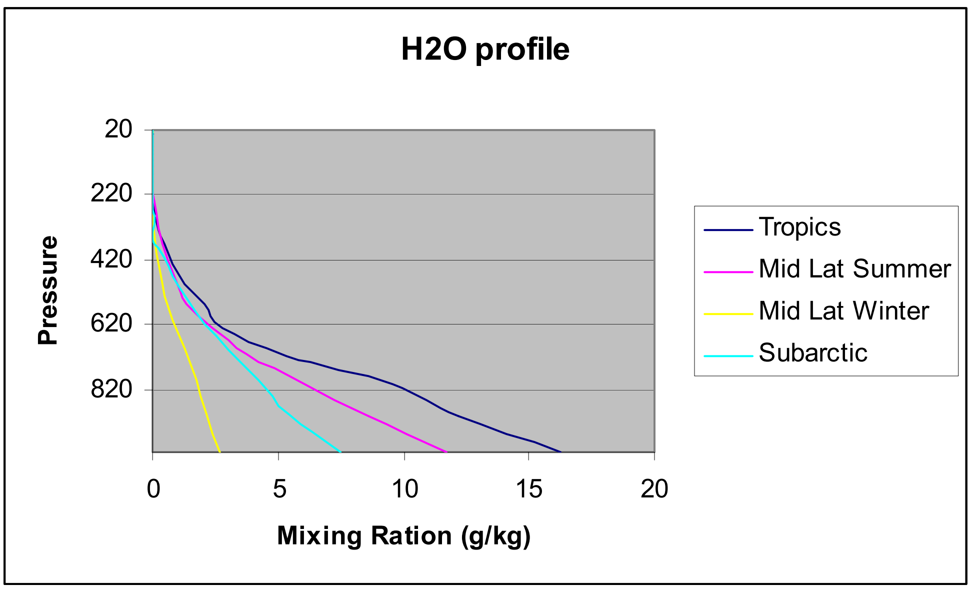


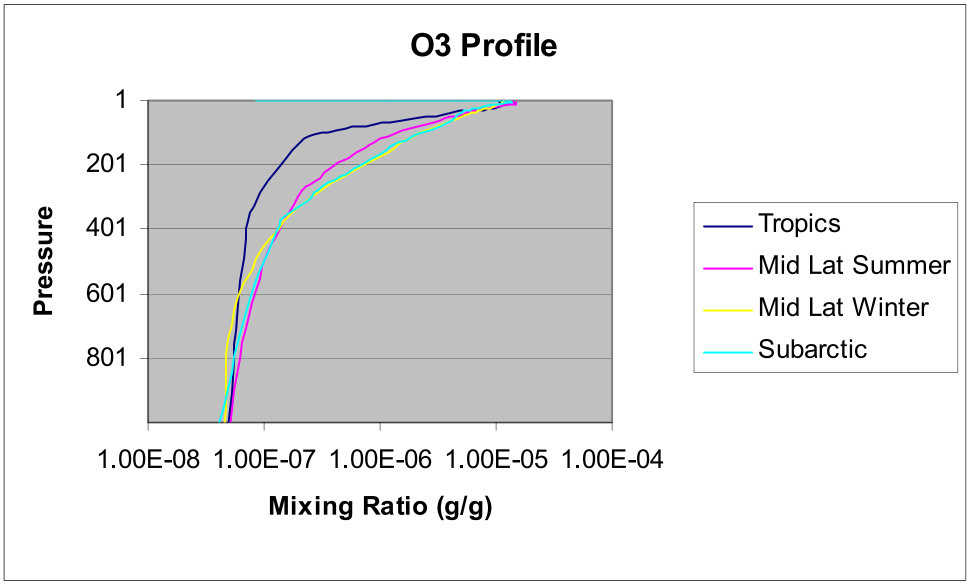
Case C is similar to case A and is different from case B. The reason is that there is very little ozone is found in the troposphere as relative to the water vapor. Thus, ozone does not contribute much to the fluxes in the troposphere (small increase in upward flux due to absence of ozone absorption).

TASK 2

A) *For the Tropical Atmosphere, Midlatitude Summer Atmosphere, Midlatitude Winter Atmosphere, and Subarctic Summer Atmosphere, calculate the IR net fluxes at the surface, near tropopause, and top of the atmosphere. Then calculate and compare the net flux divergence (ΔF_{net} in W/m2) in the troposphere and above. Explain your results.*


Net Flux
20
220
420
620
820
Pressure
0
100
200
300
Flux (Up-Down)
Tropics
Mid Lat Summer
Mid Lat Winter
Subarctic


H2O profile
20
220
420
620
820
Pressure
0
5
10
15
20
Mixing Ration (g/kg)
Tropics
Mid Lat Summer
Mid Lat Winter
Subarctic



	Net flux			Flux convergence	
	Surface (1013 mb)	Tropopause (200 mb)	TOA (0 mb)	DFnet (trop)	DFnet (strat)
Tropical	85.98	253.5	274.87	169.25	19.64
Mid-lat Summer	92.95	238.2	267.5	145.57	28.98
Mid-lat Winter	94.74	188.88	217.85	94.38	28.73
Subarctic Summer	99.51	213.97	252.37	116.08	36.78

The net flux at the surface is the sum of upward and downward fluxes. The upward flux is controlled by emission of the surface, which depends on the temperature of the surface. The downward flux is controlled by the emission due to the abundance of water vapor in the troposphere.

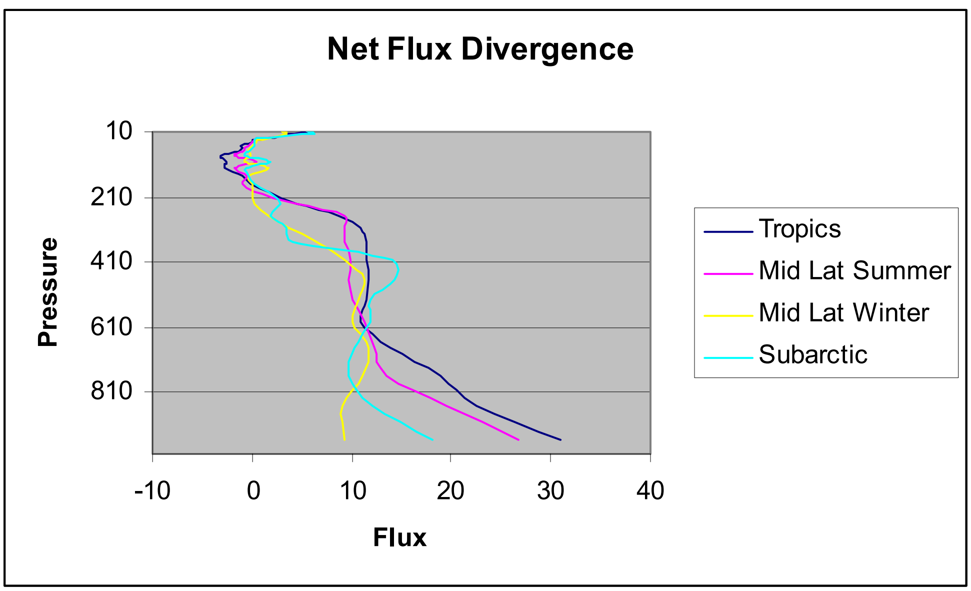
The tropical troposphere contains the largest amount of water vapor in the troposphere (the largest downward flux), and has the warmest temperature as compared to other atmospheres (the largest upward flux). However, the difference in the water vapor amount affects the downward flux stronger than the difference in the surface temperature affects the upward flux. Thus, the net flux results show that the surface at the tropical atmosphere has less net energy than surface for subarctic summer.

The net flux at the tropopause is mostly controlled by emission/absorption by tropospheric water vapor (through upward flux), cold temperatures at tropopause (smaller emission) and by amount of ozone in the stratosphere (through the downward flux). The upward flux is large (large H2O emission), whereas the downward flux at the tropopause is small (cooler temperature and reduced flux due to ozone absorption in the stratosphere).

The net flux at the top of atmosphere is similar to the flux at tropopause, but slightly higher due to the water vapor, ozone and CO2 emissions in the stratosphere.

The IR flux divergence is higher in the troposphere (F_{net}(tropopause)-F_{net}(surface)), than in the upper atmosphere (F_{net}(TOA)-F_{net}(tropopause)). This is due to the relatively higher abundance of the water vapor in the troposphere than in stratosphere. The tropical troposphere contains the largest amount of water vapor in the troposphere (the largest downward flux), and has the warmest temperature as compared to other atmospheres (the largest upward flux). Thus, the net flux divergence in troposphere is largest for tropical atmosphere, and the smallest for mid-latitude winter atmosphere.

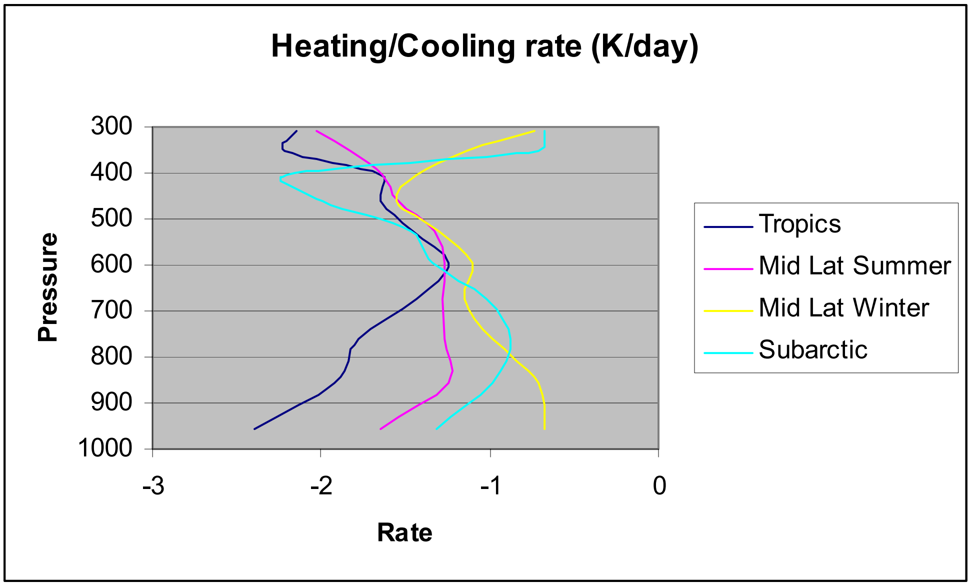
The flux divergence in upper atmosphere (above the tropopause) is mostly controlled by emission/absorption by troposphere water vapor (through upward flux), cold temperatures at tropopause (smaller emission) and by amount of ozone and CO2 in the stratosphere (larger emission at warmer temperatures). Since there is more ozone in the arctic summer atmosphere, and stratospheric temperature is the warmest among all cases, it causes the largest emission due to ozone and CO2, and thus creates the largest stratospheric divergence among all cases. The difference between mid-latitude summer and winter is due to the fact that cooler stratospheric temperatures are found in winter than in summer.



B) *Consider the Midlatitude Summer Atmosphere. Note that the flux divergence over the entire atmosphere does not equal the flux emitted at the top of the atmosphere –what else is cooling, i.e. what makes the longwave flux balance?*

The net flux divergence in the mid-latitude summer atmosphere is 174.55 W/m^2. The flux divergence shows how much energy is related to the atmosphere only. The flux emitted at the top of atmosphere (271.48 W/m^2) also includes the flux emitted by warm surface (92.95 W/m^2) as well as small contribution from near IR solar flux (about 4 W/m^2).

C) *Plot and compare IR heating/cooling rates calculated for these atmospheres in the 10 lowest layers. Explain main differences.*



There is an inversion of cooling rates with altitude at about 600 *mb* pressure level. The reduction in the cooling rates with altitude up to 600 *mb* is related to the reduction of water vapor concentration and temperature. Above 600 *mb* pressure level, the rate of reduction of water vapor mixing ratio and temperature with altitude slows down. At the same time ozone concentration starts to increase above 600 *mb*, thus increasing emission and cooling rates. The largest cooling rate at the surface is found for tropical troposphere (below 300 *mb*) due to the highest amount of water vapor. The warm temperature of the surface also increases emission, thus increasing cooling rates. Middle latitude winter case has the lowest cooling rate because it has the driest and the coldest lower troposphere. At 300 *mb* level, the cooling again corresponds to the emission of water vapor: there is significantly less water vapor in both cases of subarctic and mid-latitude winter atmospheres, thus less cooling.

TASK 3

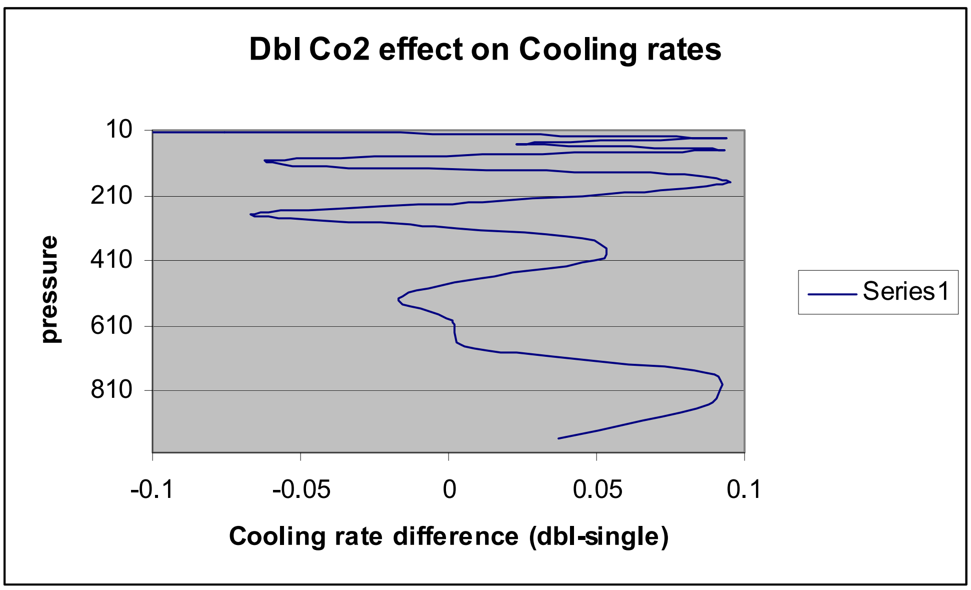
A) *Investigate how a doubling of the present CO_2 concentration affects the IR fluxes at the top of the atmosphere (TOA) and at the surface for the Midlatitude Summer Atmosphere, by calculating the change in the downwelling fluxes at the surface and the change in TOA upwelling fluxes. Briefly explain your results.*

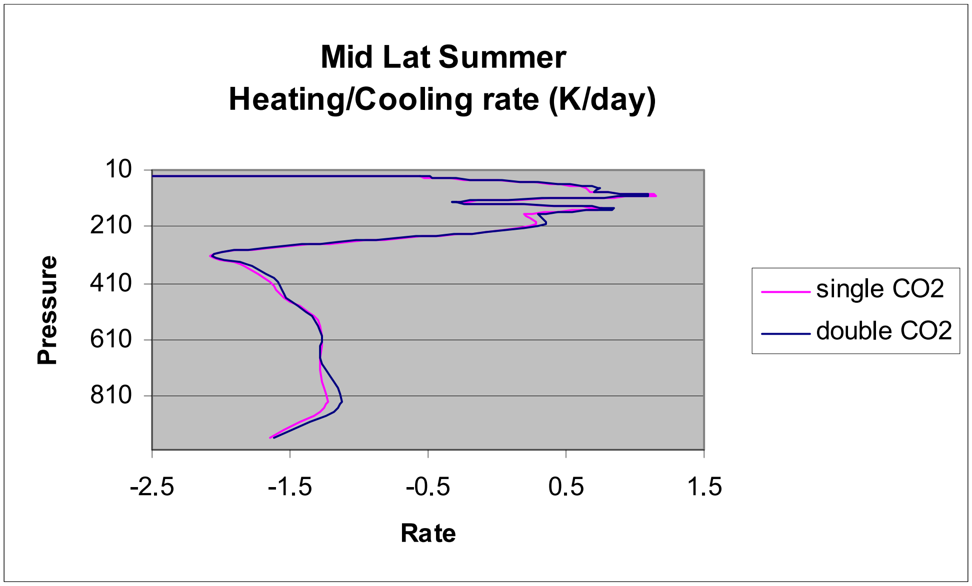
The doubling of CO_2 concentration (in troposphere) increases the downward flux at the surface (from 330.6 to 334.24 W/m^2, extra emission) and decreases upward flux at the

TOA (from 271.48 to 267.7 W/m^2, CO_2 is trapping the upward flux at the top of atmosphere). This effect is known as greenhouse effect.

B) *Calculate and plot the difference between the IR radiative heating rate profile for doubled CO_2 and present CO_2 cases. (Consider pressure up to 10 mb). Explain the change in the IR heating rate profile.*

The atmosphere in IR looses energy through thermal emission processes. The IR cooling rates are defined by vertical distribution of water vapor, ozone and CO_2, as well as temperature vertical distribution (cold tropopause and warm surface and stratopause). The CO_2 mixing ratio is the largest in stratosphere as compared to ozone and water vapor, while in troposphere the water vapor is abundant. The largest cooling rates produced by water vapor are found in troposphere (large amount of water vapor) and middle atmosphere (warm temperature). In the middle atmosphere cooling rates are generated by CO_2 emission, which strongly depends on temperature (warmer temperature means stronger emission). The cooling rates due to O_3 are defined by ozone concentration, which is the largest in the stratosphere (about 20-25 km). The large amount ozone in stratosphere causes small amount of positive heating.





The amount of CO2 in standard atmosphere is already large. Therefore, the doubling of CO2 cannot produce large effect on fluxes. The plot shows that the main difference is observed in the lower troposphere around 800 *mb* level. There is less cooling above the doubled layer than it is for a single layer. The reason is that doubling of CO_2 increases the downward flux due to increased emission; whereas absorption is already large and upward flux does not change much. Therefore, the net flux at the pressure level (difference between upward and downward fluxes) and divergence in the layer between top and bottom boundary levels are slightly reduced. Thus, doubling of CO_2 reduces cooling in some layers and in the lower troposphere (up to 300 *mb*) in general.

In the stratosphere, the net flux divergence increases due to increase of temperature with altitude, and, thus, there is an increases in emission and relative increase in cooling rates. Ozone concentration increases in the stratosphere; as result some heating occurs due to ozone absorption, which reduces cooling at about 20-25 km and creates zigzag in difference between cooling rates. Still, ozone emission increases above its maximum in stratosphere, where the maximum in ozone cooling rates found at the stratopause. CO_2 emission increases with altitude reaching maximum cooling rate at the tropopause, whereas a doubling of CO_2 increases cooling rates even furthermore. Thus, the whole stratosphere (above 200 *mb*) is a bit cooler (by about 0.5 degree per day) due to increase in CO_2. Therefore, cooling in the upper atmosphere offsets heating in the troposphere, and, thus, doubling of CO2 does not produce significant warming of the entire atmosphere.